

# CHANGES IN TOBACCO-RELATED MORTALITY DUE TO REDUCED EXPOSURE PRODUCTS: A dynamic population model to estimate the potential efficacy of tobacco harm reduction approaches

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## ABSTRACT

**Purpose:** The potential for harm reduction to result from replacing 0 to 100% of smoked cigarettes with smokeless tobacco has received considerable attention. This paper introduces a model that estimates changes in hypothetical population mortality associated with different tobacco exposure scenarios.

**Methods:** We created a computer simulation that estimates mortality for a hypothetical population of persons who have never used tobacco and who, as they age, may transition into and out of different tobacco exposure states, including current and former smoking or smokeless tobacco use. Markov Chain Monte Carlo techniques estimate the variability of the results.

**Results:** All model inputs, including population exposure and mortality parameters for the base case; comparative risks for various tobacco products; and age-specific transition probabilities, are user-specified. The model allows for 33 possible transitions into and out of tobacco exposure states, tracks individual exposure histories, and estimates age- and exposure-history-specific mortality. For each age group and at the end of follow-up, the model estimates the number of survivors comparing the base case with the hypothetical exposure scenario, and calculates the difference. The model was tested against both US and Swedish life tables, with population-specific exposure transition probabilities derived from the literature, and it produced comparable results.

**Discussion:** This model's main strengths are its comprehensiveness and flexibility. We expect it to be useful for development of harm reduction policies, because it will help to clarify assumptions underlying the arguments for and against policies being considered.

## INTRODUCTION

*Harm reduction:* greater health gains are achieved by modifying existing behaviors than by attempting to eradicate those behaviors.

*Tobacco harm reduction (THR):* reduction in harm expected to result from reduced exposure to tobacco toxins. THR can be achieved through:

- Less use of tobacco products
- Substitution of less harmful products (e.g., potentially reduced exposure products [PREPs] for cigarettes)

No US population data exist to support or refute the efficacy of THR policies that promote PREPs. Experimental evidence and ecological data from Sweden suggest health benefits for cigarette smokers who switch to PREPs, but there may be unintended consequences of PREP-promoting policies:

- Some smokers who would have quit may instead use PREPs
- Some non-tobacco users who would not smoke may begin using PREPs

Models can be used to estimate the effects of different tobacco use patterns (PREP use or non-use) on population mortality. Several models already exist, but can be improved with respect to:

- Validity of estimates, assumptions
- Flexibility to model different exposure patterns, outcomes
- Comprehensiveness of allowable transitions

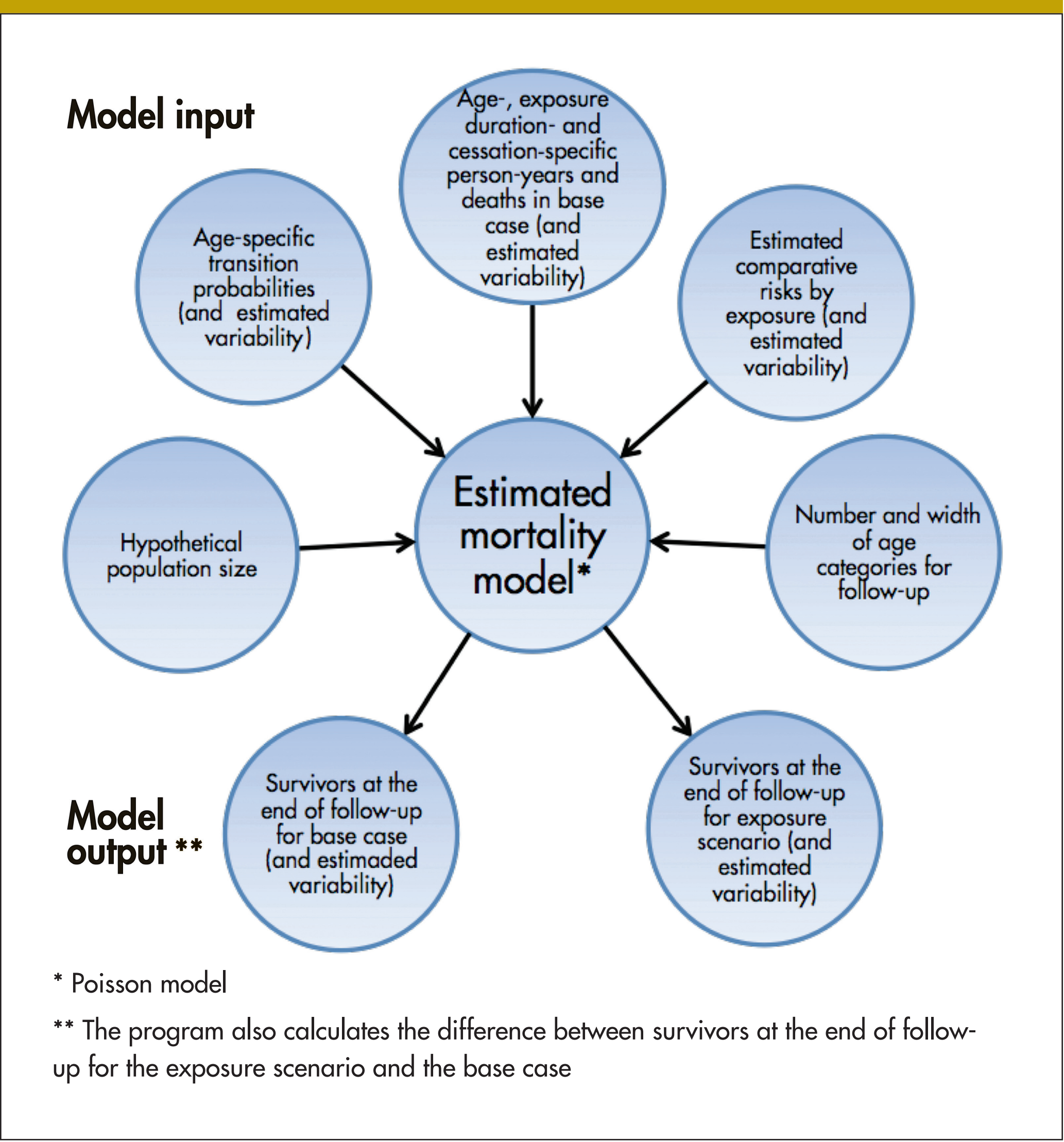
## General Approach

A hypothetical population of never smokers of age  $a_{start}$  is followed to age  $a_{end}$ .

Up to 33 different transitions into and out of tobacco exposure states:

- Remaining a never-tobacco user until the end of follow-up
- Use of only cigarettes or only PREP
  - Until the end of follow up
  - Until cessation and, in case of relapse, from relapse to the end of follow up or until 2nd cessation
- PREP use followed by cigarette smoking (or vice versa)
  - Until the end of follow up
  - Until cessation of all tobacco use
  - Until relapse to PREP use (or smoking) with use until the end of follow-up or until cessation of all tobacco use
- PREP use or cigarette use followed by dual use
  - Until the end of follow-up
  - Until cessation of all tobacco use

FIGURE 1. Model input and output



Deaths are estimated using:

- A core Poisson mortality model based on age -, duration of smoking- and duration of quitting-specific person-years and deaths from a population of interest
- Estimates of the mortality risk for PREP users compared to cigarette smokers

At the end of each age category, the program produces:

- The number of survivors assuming the PREP is not available (the base case)
- The number of survivors assuming the PREP is available and used with a given set of transition probabilities (the exposure scenario)
- The difference in the number of survivors comparing the base case and exposure scenario

## Statistical approach and software

The model is implemented in WinBUGS (version 1.4.3).

WinBUGS allows for estimation of the variability of all model outputs using Markov Chain Monte Carlo techniques.

The number of survivors is estimated after each model iteration and summarized over all iterations using means and 95% posterior intervals (2.5th and 97.5th percentile of the distribution).

## MODEL VALIDATION

The life tables created by the model provided good approximations of actual population life tables.

Depending on data availability, other countries and years could have also been used to validate the model.

Model validation was a component of model development and does not have to be repeated by the model user.

**Hypothetical population:** 1,000,000 12-year old males, never used tobacco  
**Follow-up:** From age 13 to age 72 years, 5-year age intervals

**FUNDING SOURCES:** This model was developed independently, and the conclusions are solely those of the authors. Major support was provided by R J Reynolds Tobacco Company Company (Winston-Salem, NC). Additional support was provided by Swedish Match (Stockholm, Sweden).

## Results of validation

Comparison of age category-specific estimated numbers of survivors: 2006 US life table for men versus base case model estimates (starting with 1,000,000 12-year old male never tobacco users)<sup>1</sup>

Age category	Survivors based on US life table	Survivors based on base case model (US)
38-42	957,654	958,800
43-47	940,866	940,900
48-52	915,745	915,800
53-57	880,470	880,800
58-62	832,268	832,100
63-67	764,922	764,500
68-72	674,217	671,800

<sup>1</sup> Age group 38-42 is the 1st age group where all possible transitions have occurred

Comparison of age category-specific estimated numbers of survivors: 2006 Swedish life table for men versus full model estimates (starting with 1,000,000 12-year old male never tobacco users)<sup>1</sup>

Age category	Survivors based on Swedish	Survivors based on base case model life table (Sweden)
38-42	980,999	980,674
43-47	972,889	971,210
48-52	959,782	957,976
53-57	936,838	935,577
58-62	902,590	900,804
63-67	846,884	844,862
68-72	764,275	759,182

<sup>1</sup> Age group 38-42 is the 1st age group where all possible transitions have occurred

## STRENGTHS

**All model input can be changed easily by the user**

- Number and width of the age categories
- Exposures of interest
- Outcome of interest
- Excess relative risk of each outcome for each new product (i.e., PREPs) compared to the status quo product (i.e., cigarettes)
- Hypothesis to be tested (through age category-specific transition probabilities entered by the model user)
- Estimate of certainty about input data
- As epidemiological data become available, model input can (should) be revised

## RUNNING THE MODEL: Estimating the difference in mortality expected under two exposure scenarios

**Illustration of the model's capabilities; not an attempt to estimate survival changes in a real population**

1,000,000 12-year old male never tobacco users followed to age 73 under two exposure scenarios

- Less common snus use (similar to Sweden prior to 1980)
- Common snus use (similar to Sweden after 1980)
- 1980 selected for convenience

## Results of illustrative model run

Age category-specific estimated mean difference between numbers of survivors (base case and full model) with 95% posterior intervals (PI) (starting with 1,000,000 12-year old male never tobacco users)

Increased snus use after 1980 led to about 20,000 fewer deaths. Results depend on the underlying tobacco use patterns and comparative risk estimates.

Age category	Mean difference <sup>1</sup>	95%	PI
38-42	767	-1,50	1,765
43-47	1,701	129	3,387
48-52	3,325	831	5,979
53-57	5,865	2,142	9,775
58-62	9,475	4,272	14,890
63-67	14,110	7,366	21,060
68-72	19,340	10,980	27,790

<sup>1</sup> Mean difference between the number of survivors under two exposure patterns, Sweden, pre- and post-1980, assuming 1,000,000 12-year olds are followed through age 72

## Flexibility

- No restrictions placed on age, time of initiation or time of cessation of tobacco product use

**Accounts for level of uncertainty in the model input**  
**Model output can be used for tipping point analyses**

## Comprehensiveness

- 33 possible transitions between tobacco exposure states, including dual use and relapse
- Estimates the number of survivors at the end of each age category for each exposure history up to that point

**Validated against two populations**

## LIMITATIONS

Precision depends on certainty in the model input.

Most transition probabilities are unknown and uncertainty in the model results is considerable.

Currently cannot be used to investigate the effect of removing an exposure that exists in the base case.

## CONCLUSIONS

As empirical data on transitions among exposure categories and comparative risk estimates for various products become available from real populations, the model will become more useful in its ability to inform policy decisions due to the increase in precision and validity of model input.

The model is already useful for development of harm reduction policies because it can estimate the effect of intended and unintended consequences of THR policies under varying assumptions about tobacco use patterns, and it allows for tipping point analyses.

